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Scale-up of Hydrogen Transport Membranes for IGCC and FutureGen Plants

Presented by

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This presentation does not contain any proprietary or confidential information.

#PD13

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Overview

Timeline

- Project start date: 1 Oct 2005
- Project end date: 30 Sep 2010
- 5% percent complete

Budget ($000)

- Total project funding: $15,300
  - ✓ DOE share: $12,240
  - ✓ Contractor share: $ 3,060
- Funding received in FY05: $ 0
- Funding for FY06: $ 966

Barriers Addressed

- Reducing hydrogen cost
- Hydrogen production from diverse pathways
- Hydrogen of sufficient purity for fuel cells

Technical Targets

- Low-cost H_2 production system to produce CO_2 and H_2 from coal-derived synthesis gas
- Demonstrate in 220 lb H_2 /day unit
- Design for 4 ton/day unit
- Tolerant to syn gas contaminants

Partners

- NORAM Engineering
- CoorsTek
- Praxair

DOE Contract DE-FC26-05NT42469

Objectives

- Continue Vision 21 project for high-throughput, low-cost H_2 separation system: scale-up and improve tolerance to contaminants (S, Hg, etc.)
- Determine optimum mechanical configuration (tube vs. plate; metal vs. cermet) based on manufacturability, cost & performance of membrane and system
- Scale up membrane & system from 0.45 lb/day of H_2 using lab gases to 220 lb/day in coal-derived syn gas
- Integrate membrane design into a 4 ton/day H_2 production unit
- Determine optimum process design & cost and compare vs. other systems

Advances in Past Year

- Process Design and Cost Estimating
- 1,000 psi ΔP across membrane
- Elimination of sweep gas
- Outlet Pressure up to 270 psi
- Initial testing of Sulfur tolerance to 200 ppm
- Excellent results of integrating Water-Gas Shift into membrane reactor (separately funded SBIR project)

Current Performance Results

- 99.999%+ H_2 selectivity consistently
- Demonstrated 1,000 psi ΔP
- Demonstrated 270 psi permeate pressure (limited by experimental setup)
- 11 months continuous operation in a simulated synthesis gas stream containing H_2, CO, CO_2 and H_2O (steam)
- Eltron H_2 flux = 423 ml/min-cm^2 (Pd = 15, Pd-Cu alloy = 8)
- Flux rates validated by DOE NETL

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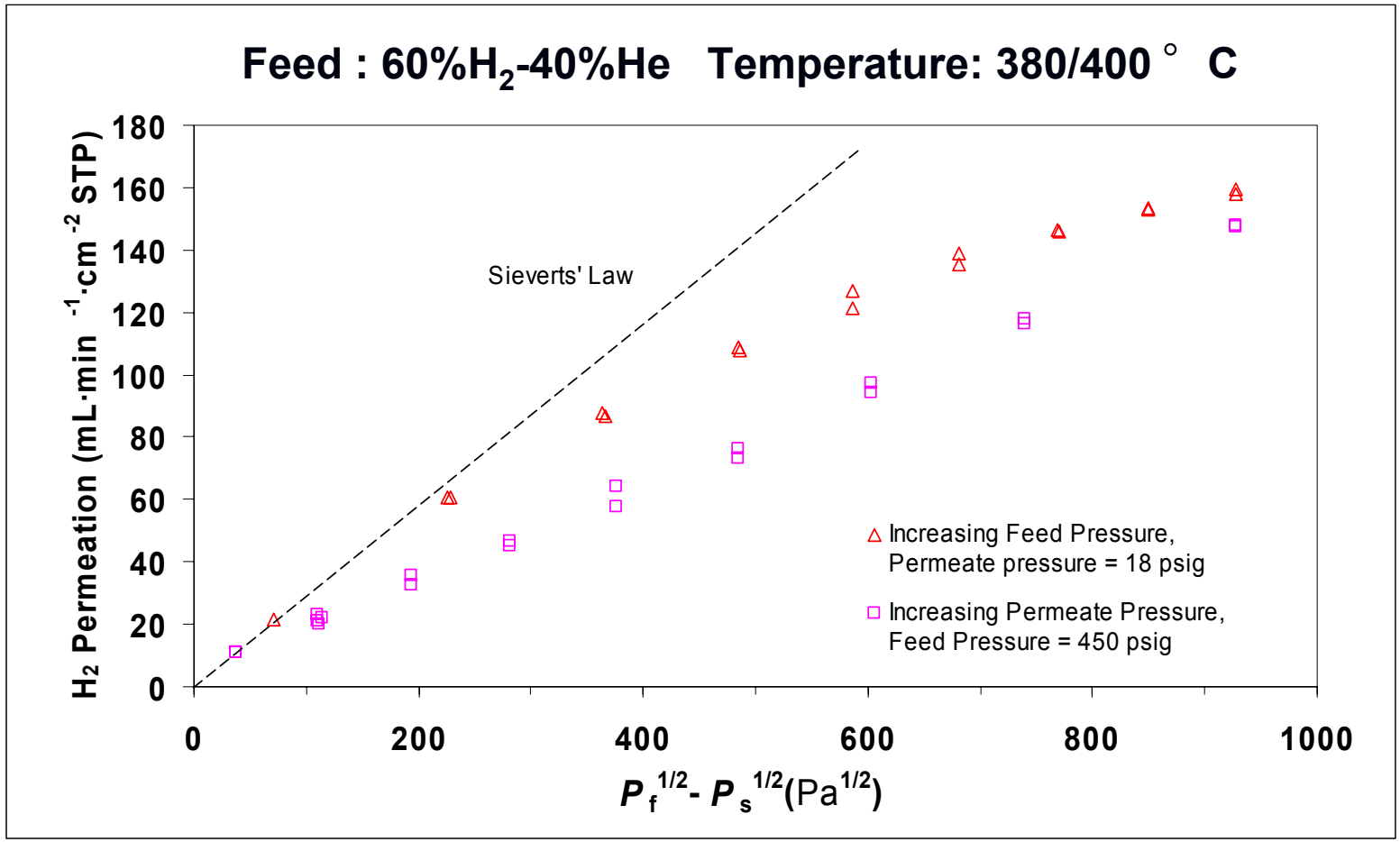
Recent Flux Data



Outlet pressure ranged from 0 – 275 psig

Sieverts' Law deviation – gas phase diffusion limited (reactor configuration)

not **membrane limited**

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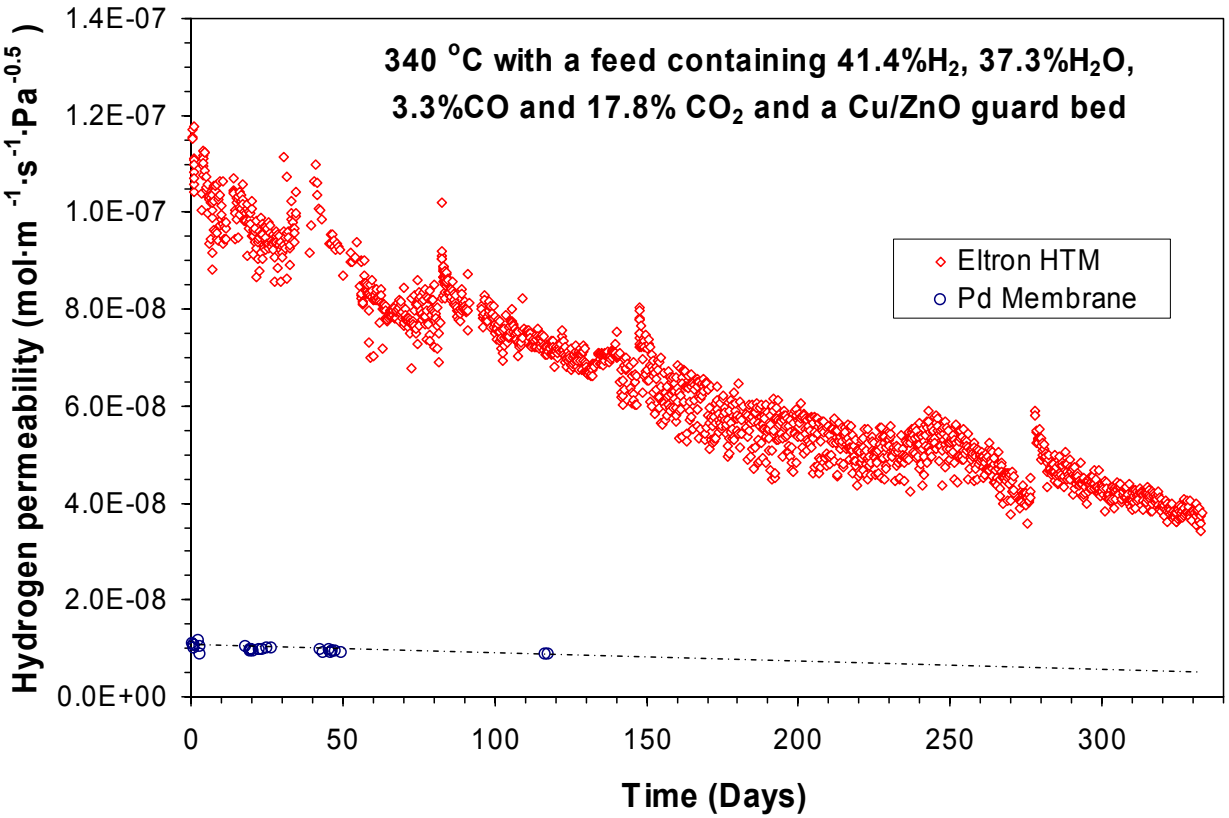
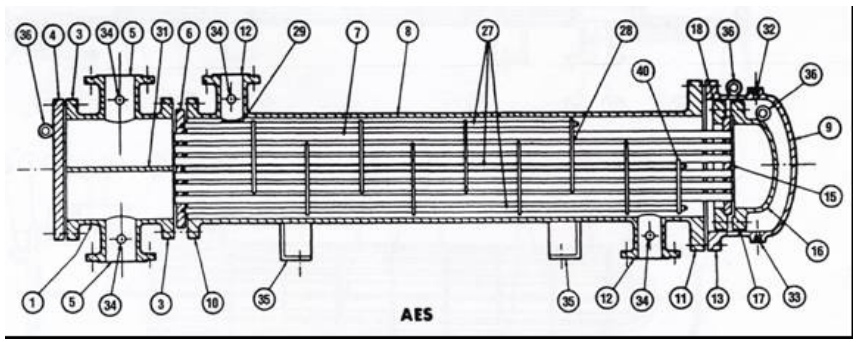
Membrane Long-Term Stability under WGS Conditions



- One of few known membrane studies that was conducted for 11 months under a simulated WGS conditions.
- Still about five times better than Pd membrane after one year operation.

Vision 21 Process Modeling Results (NORAM)

- 35 TPD H_2 Separator Unit
  - ✓ Tubular Heat Exchanger Type Geometry
  - ✓ $21K Capital / TPD H_2
- x8 = 265 TPD H_2 FutureGen
- Total Incremental System Cost ~ $23 M
  - ✓ Includes membrane cost, separator assembly / installation, gas cleaning, H_2 cooling
- For Comparison
  - ✓ PSA ~ $41M



Source: ASME VIII, Div. 1, Section UHX

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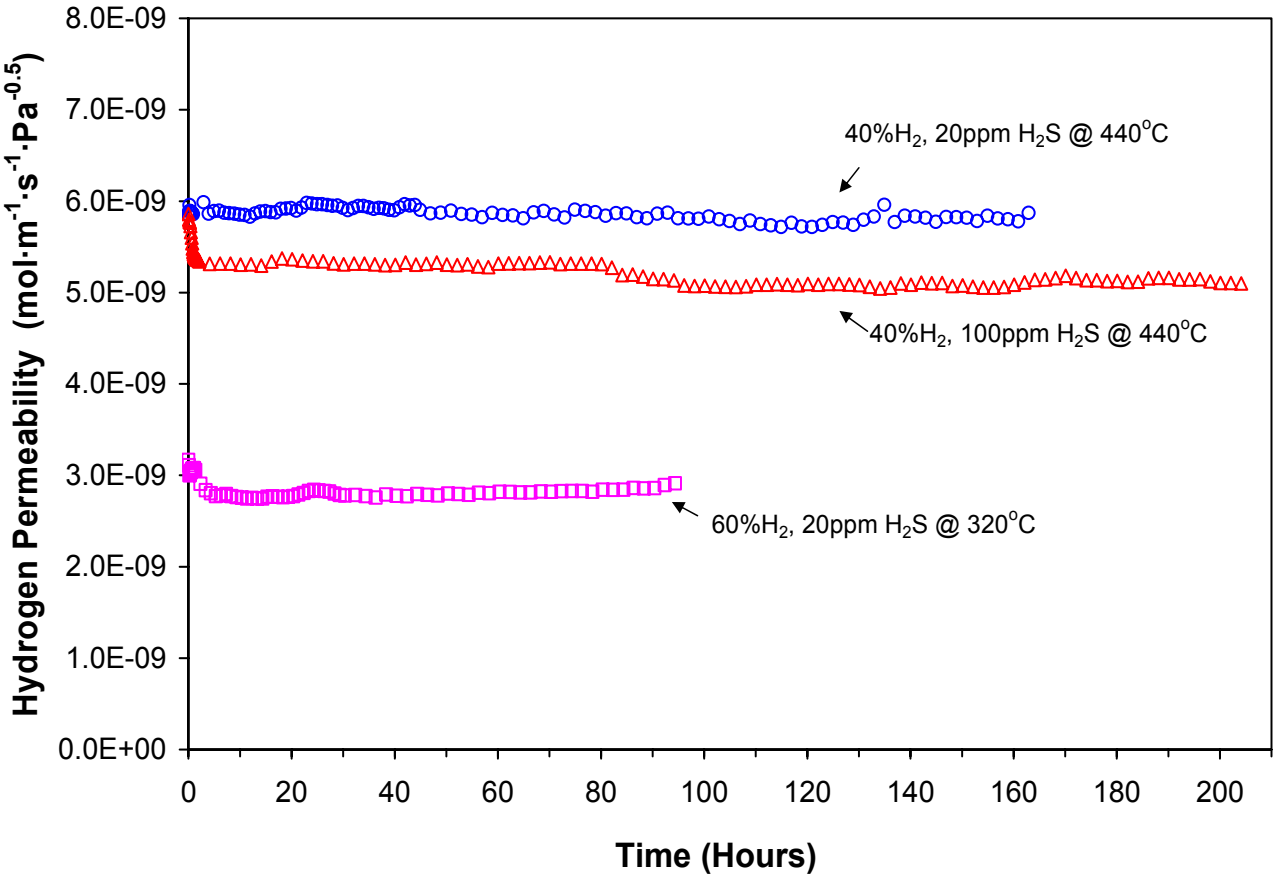
Sulfur Tolerance of an Alloy Catalyst



- **Several alloy catalysts display a good stability with a 40% H_2 stream containing 20 ppmv of H_2S.**
- **Emerging warm-gas cleaning technology can clean sulfur impurity below 2 ppmv.**

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Progress Towards DOE FutureGen Targets

Performance Criteria	*2005 Target*	*2010 Target*	*2015 Target*	***Current Eltron Membrane***
Flux (sccm/cm^2/100 psi ΔP)	50	100	150	**160**
Operating Temperature (^{o}C)	400-700	300-600	250-500	300-400
S Tolerance (ppmv)	N/A	2	20	**20 (early)**
System Cost ($/ft^2)	1000	500	<250	**<200**
ΔP Operating Capability (psi)	100	400	800-1000	**1,000**
Carbon Monoxide Tolerance	Yes	Yes	Yes	**Yes**
Hydrogen Purity (%)	95	99.5	99.99	**>99.999**
Stability/Durability (years)	1	3	>5	0.9
Permeate Pressure (psi)	N/A	N/A	N/A	***270***

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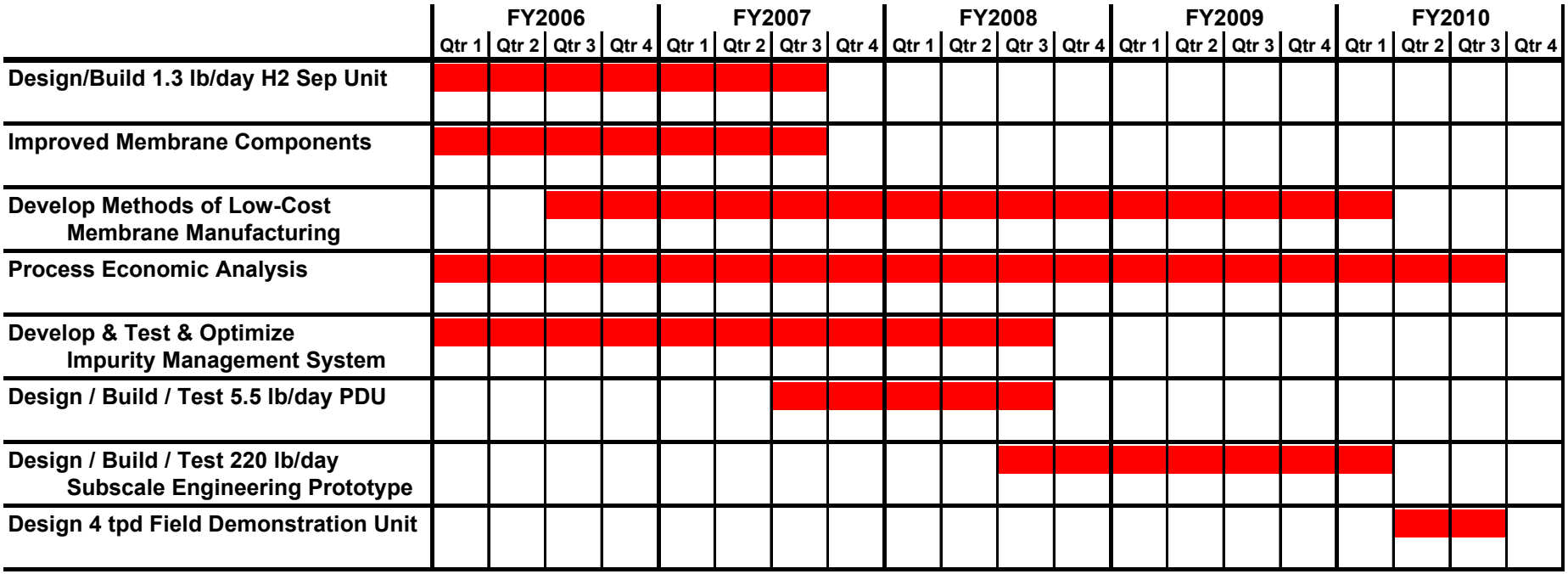
Simplified Project Schedule

Scale Up Hydrogen Transport Membranes for IGCC and FutureGen Coal to Hydrogen Production Plants



DOE Contract #DE-FC26-05NT42469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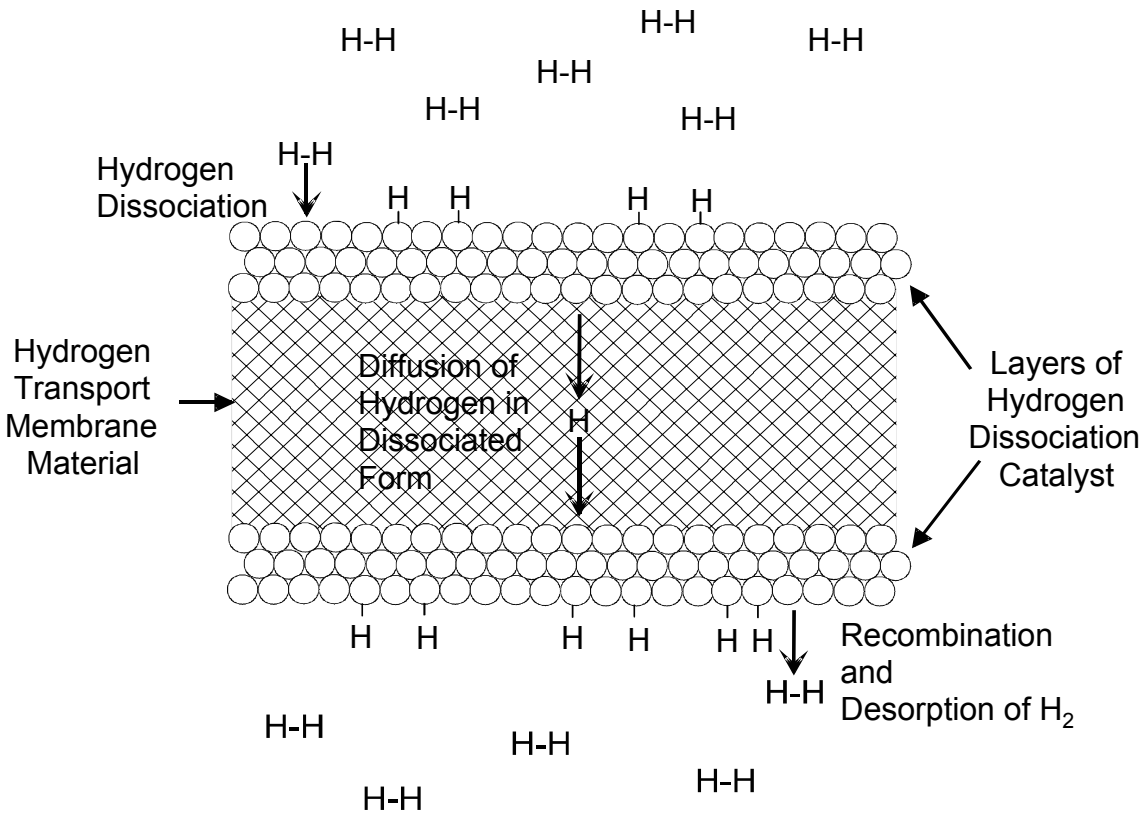
Hydrogen Transport Across Eltron's Membrane



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Sputtering System for Membrane Catalyst Deposition

Material Focus – FY06

- Top/Bottom Catalyst Layer
  - ✓Increased sulfur tolerance (alloys) [top layer]
  - ✓Optimal application to bulk membrane (CVD, Electroplating, Electroless, Sputtering)
  - ✓Tubular vs. Plate
- Bulk Membrane
  - ✓Diffusional barriers with top/bottom layers
  - ✓Cost reduction (cermets) [with CoorsTek]

Process Design Focus – FY06

- Eltron System
  - ✓ Staged WGS/HTM optimum balance
    - ❖ Number of stages
    - ❖ Permeate pressure per stage
    - ❖ Membrane size (hence throughput) per stage
    - ❖ Heat management issues (if any)
  - ✓ Operability
    - ❖ Start-up, shutdown, run-times
  - ✓ Refined Capital & Operating Cost Estimation
- Comparison to Other H_2 &/or CO_2 Systems
  - ✓ Pressure Swing Absorption
  - ✓ Post-combustion amine scrubbing

Note – Above with NORAM & Praxair

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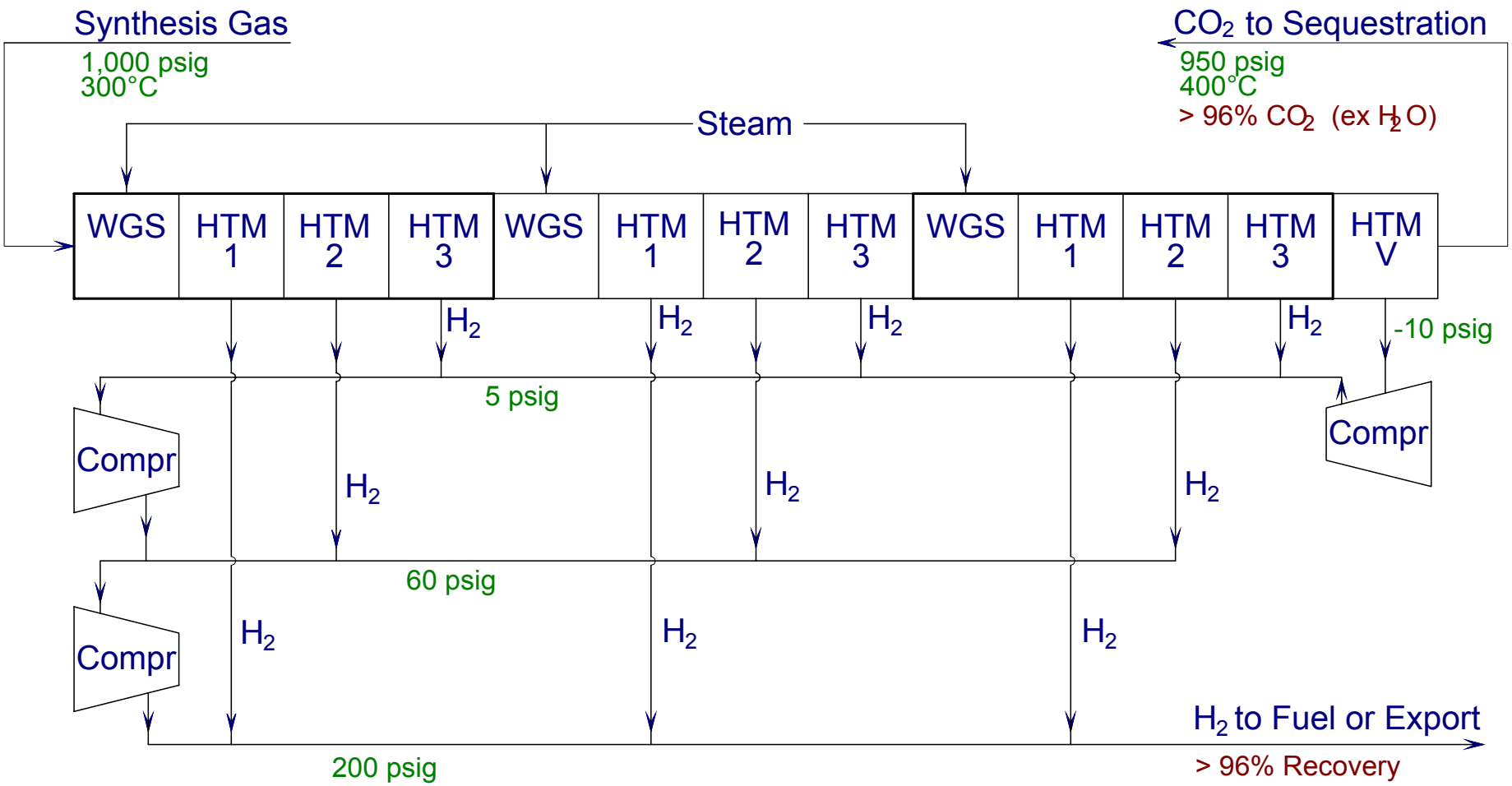
Simplified Flowsheet Staged WGS / HTM System Maximum H_2 and CO_2 Production



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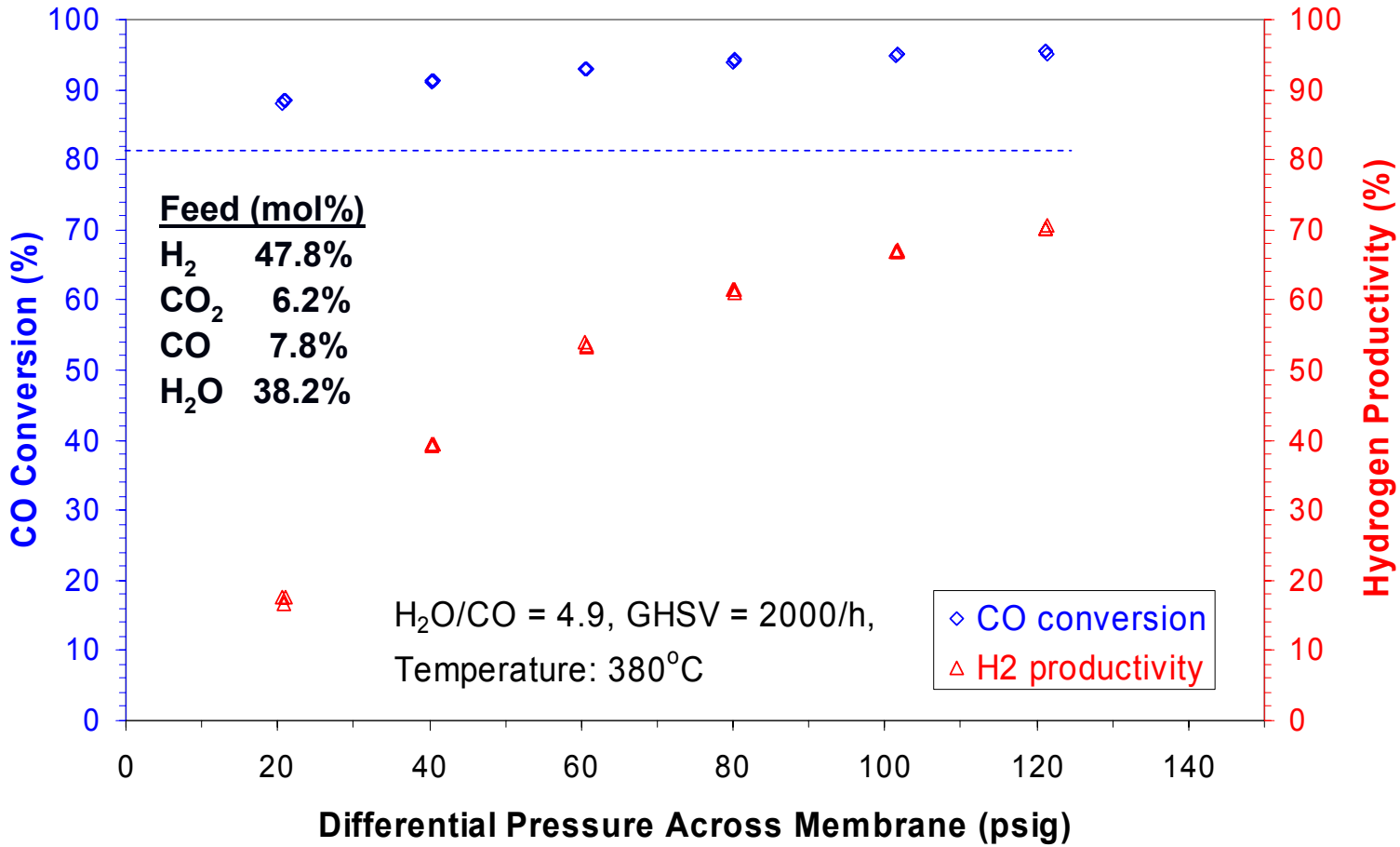
Integrated WGS / HTM Conversion "Beyond Equilibrium"

F81-34AB



Challenge for Funding

- Contract between Eltron & DOE is for first 2 years only. Last 3 years will be committed after a replacement subcontractor has been identified.

- Eltron is in discussions for participation with 25+ companies including coal and energy producers, technology providers, E&C's, gasifier providers, turbine manufacturers and materials suppliers.

- Eltron will likely propose to accelerate the program to skip the 5.5 lb/day unit and add a functioning 4 ton/day unit (instead of the current paper design) when the new partner(s) is finalized.

Summary

- Eltron's membrane continues to show stable, high fluxes using relatively low-cost materials.
- Contaminant handling, durability, and fabrication are materials focus areas.
- The project has moved well beyond materials R&D into engineering and cost analysis.
- Improvements have been made in materials and process design which are leading to additional cost reductions and performance enhancements.
- The project is on schedule and budget.

Back-Up Slides

- See following slides

Response to 2005 Reviewer Comments

- **Lack of focus on durability testing prior to scale up**
  - ✓ Some sulfur testing has been done with encouraging results
  - ✓ Lifetime demonstrated at 11 months to-date
  - ✓ Lifetime testing with contaminants is part of the program

- **100% selectivity and recovery will not be achieved**
  - ✓ >99.999% selectivity is routinely achieved
  - ✓ Recovery will be based on economics which are favored by simplicity and cost of membrane system

- **No economic analysis performed**
  - ✓ Economics were run after last year's presentation that show almost a 50% improvement versus PSA
  - ✓ The CCP Team calculated that Eltron's membrane had the potential for 60% cost reduction vs post-combustion amine scrubbing and 40% better than PSA. This was before permeate pressure staging was possible due to discovery of method for higher than atmospheric permeate pressure which reduces costs by another 20%.

Recent Publications and Presentations

- ***Hydrogen Separation Membranes, A Key to Carbon Sequestration*** *- Energy Frontiers International (EFI) Conference; "Emerging Energy Technologies: State of the Art - Challenges Ahead", Orlando, FL, Feb 2006 [Paul Grimmer]*
- ***Membranes for the Purification of Hydrogen Produced from Coal-Derived Water-Gas Shift Mixtures*** *- 22nd Annual International Pittsburgh Coal Conference, Pittsburgh, PA, Sept 2005 [Michael V. Mundschau, Xiaobing Xie, Carl R. Evenson IV, Anthony F. Sammells]*
- ***Dense Membranes for Methane Conversion to Hydrogen with Carbon Dioxide Sequestration*** *- 7th International Conference on Catalysis in Membrane Reactors, Cetraro - CS, Italy, Sept. 2005 [A. F. Sammells, M. V. Mundschau, X. Xie, C. R. Evenson]*
- ***Membrane Technologies for Oxygen Production and Hydrogen Separation*** *- International Congress on Membranes and Membrane Processes (ICOM 2005), Seoul, Korea, Aug. 2005 [Arun C. Bose, Phillip A. Armstrong, A. F. Sammells, S. Elangovan]*
- ***Performance of Palladium Catalysts on Hydrogen Transport Membranes Exposed to Water-Gas Shift Reactants at High Pressure*** *- North American Catalysis Society, 19th North American Meeting, Philadelphia, PA, May 2005 [M.V. Mundschau, X. Xie, A.F. Sammells]*
- ***Advances in Hydrogen Separation Membrane Technology for the Separation of CO2 and the Purification of Hydrogen Produced from Coal*** *- 30th International Technical Conference on Coal Utilization & Fuel Systems, Clearwater, FL, April 2005 [M.V. Mundschau, X. Xie, A.F. Sammells]*
- ***Advanced Membranes for the Spontaneous Conversion of Coal to Hydrogen*** *- 21st Annual International Pittsburgh Coal Conference, Osaka, Japan, Sept. 2004 [A.F. Sammells, M.V. Mundschau, X. Xie, C.R. Evenson]*
- ***Dense Membranes for Separation of H2 from CO2 in High-Pressure Water-Gas Shift Reactors*** *- 7th International Conference on Greenhouse Gas Control Technology, Vancouver, BC, Sept. 2004 [M.V. Mundschau, X. Xie, A.F. Sammells]*
- ***Oxygen and Hydrogen Transport Membranes for Combined Hydrocarbon Reforming and Hydrogen Separation*** *- 8th International Conference on Inorganic Membranes, Cincinnati, OH, July 2004 [A.F. Sammells, M.V. Mundschau, X. Xie]*
- ***Simultaneous Hydrocarbon Reforming, Carbon Dioxide Sequestration and Hydrogen Separation Using Dense Inorganic Membranes*** *- Annual Carbon Capture and Sequestration Conference, Alexandria, VA, May 2004 [M.V. Mundschau, X. Xie, C.R. Evenson, A.F. Sammells]*
- ***Hydrogen and Oxygen Transport Membranes for Spontaneous Conversion of Coal to Hydrogen*** *- 29th International Conference on Coal Utilization and Fuel Systems, Clearwater, FL, April 2004 [A.F. Sammells, M.V. Mundschau, S.E. Roark, T.F. Barton]*